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Koch, IV

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(54) **BLADE SAFETY MECHANISM FOR OPEN ROTOR ENGINE SYSTEM**

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F01D 21/00	(2006.01)
F01B 25/16	(2006.01)
B64D 27/12	(2006.01)
B64D 45/00	(2006.01)
B64D 27/00	(2006.01)

(52) **U.S. Cl.**

CPC ***F01D 5/14*** (2013.01); ***B64D 27/12*** (2013.01); ***B64D 45/00*** (2013.01); *B64D 2027/005* (2013.01); *Y02T 50/44* (2013.01); *Y02T 50/66* (2013.01)

(58) **Field of Classification Search**

CPC F05D 2260/311; F05D 2260/32; F05D 2270/091; F01D 5/14; F01D 21/00; F01D 21/04; F01D 21/045; F01D 21/06; B64D 2027/005; B64D 27/12; B64D 45/00; Y02T 50/66; Y02T 50/44; F42B 3/124; F42B 3/13

USPC 415/9; 416/2; 102/202.7

See application file for complete search history.

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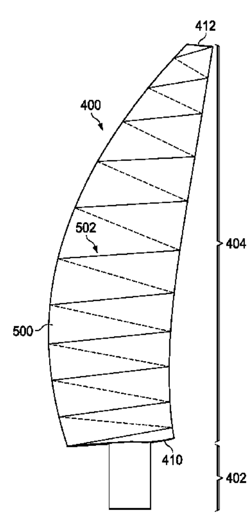
(57) **ABSTRACT**

A method and apparatus for safely handling an undesired blade event in an open rotor engine system. In one illustrative embodiment, an occurrence of an undesired blade event in an open rotor engine system is detected. Electrical energy is allowed to flow into a conductor embedded in the blade in response to the undesired blade event. The conductor is vaporized when the electrical energy flowing through the conductor heats the conductor to a temperature above a selected threshold.

20 Claims, 7 Drawing Sheets



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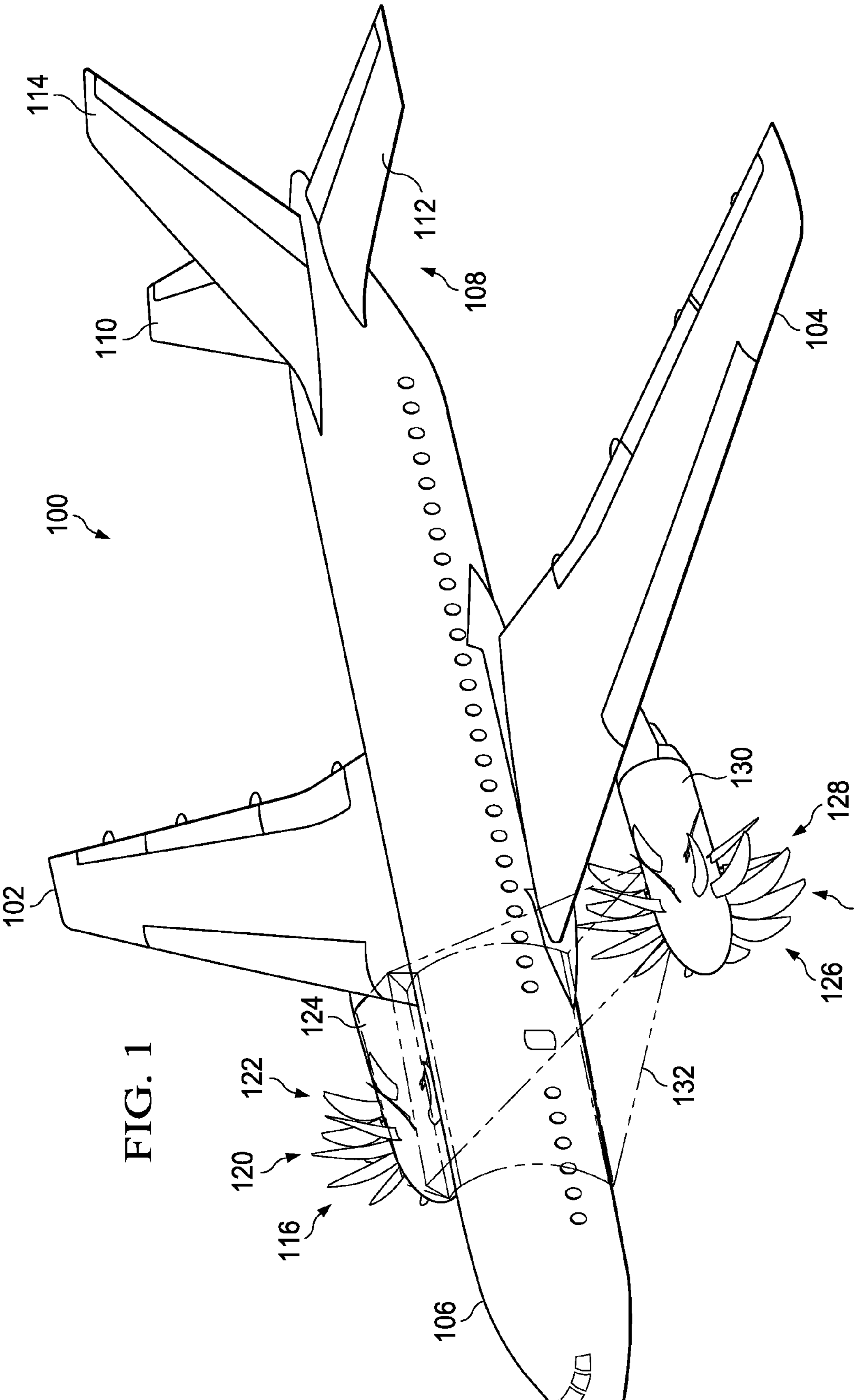
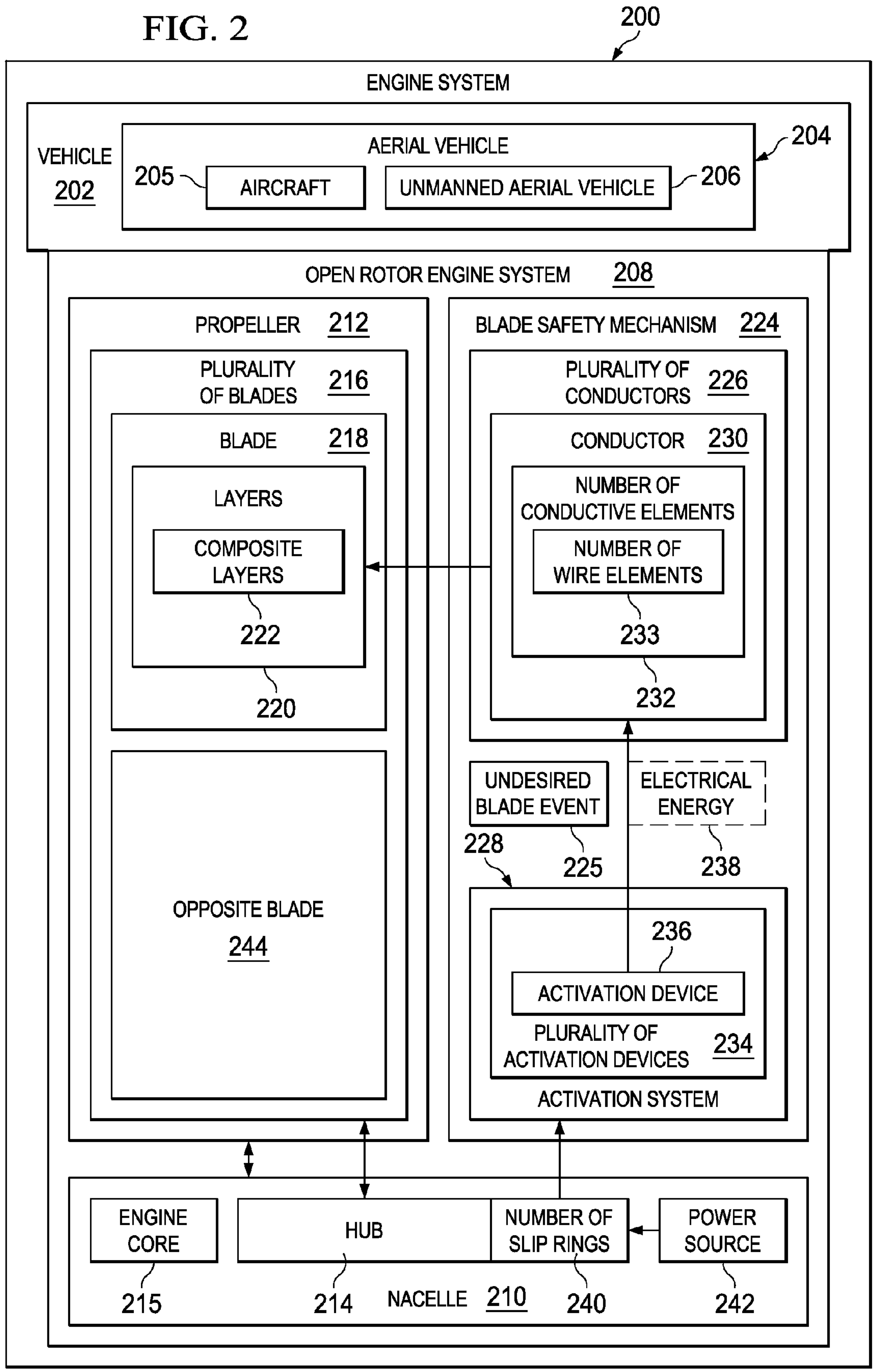

114
112
108
110
104
100
130
128
102
118
126
124
122
132
120
116
106

FIG. 1

FIG. 2


200
ENGINE SYSTEM
VEHICLE
202
AERIAL VEHICLE
204
205
AIRCRAFT
UNMANNED AERIAL VEHICLE
206
OPEN ROTOR ENGINE SYSTEM 208
PROPELLER 212
PLURALITY OF BLADES 216
BLADE 218
LAYERS
COMPOSITE LAYERS
222
220
OPPOSITE BLADE
244
BLADE SAFETY MECHANISM 224
PLURALITY OF CONDUCTORS 226
CONDUCTOR 230
NUMBER OF CONDUCTIVE ELEMENTS
NUMBER OF WIRE ELEMENTS
233
232
UNDESIRED BLADE EVENT
ELECTRICAL ENERGY
228
225
238
236
ACTIVATION DEVICE
PLURALITY OF ACTIVATION DEVICES 234
ACTIVATION SYSTEM
ENGINE CORE
HUB
NUMBER OF SLIP RINGS
POWER SOURCE
215
214
NACELLE 210
240
242

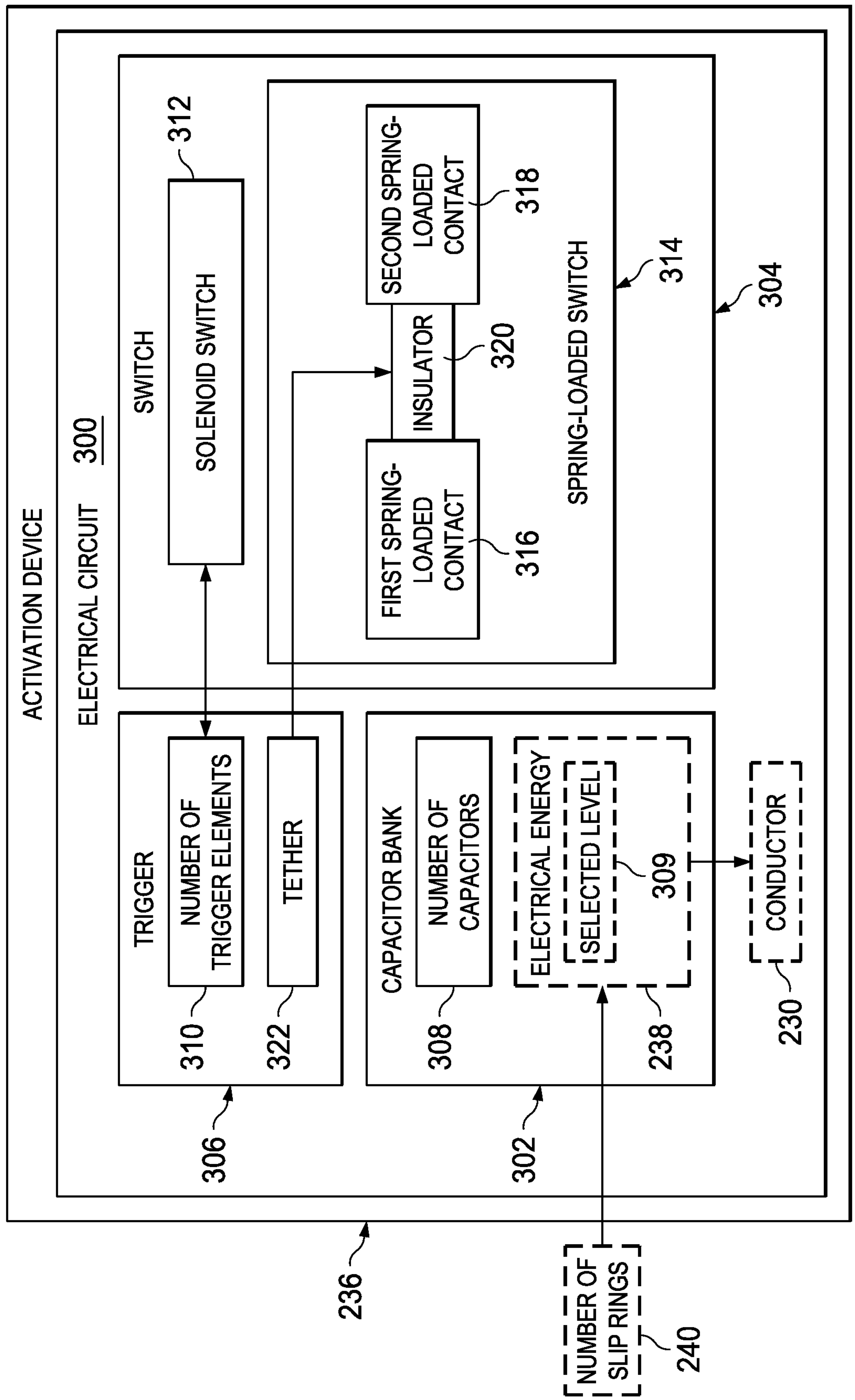

ACTIVATION DEVICE
ELECTRICAL CIRCUIT
300
SWITCH
SOLENOID SWITCH
312
SECOND SPRING-LOADED CONTACT
318
INSULATOR
320
FIRST SPRING-LOADED CONTACT
316
SPRING-LOADED SWITCH
314
304
TRIGGER
NUMBER OF TRIGGER ELEMENTS
310
TETHER
322
306
CAPACITOR BANK
NUMBER OF CAPACITORS
308
ELECTRICAL ENERGY
SELECTED LEVEL
309
238
302
CONDUCTOR
230
236
NUMBER OF SLIP RINGS
240

FIG. 3

FIG. 4

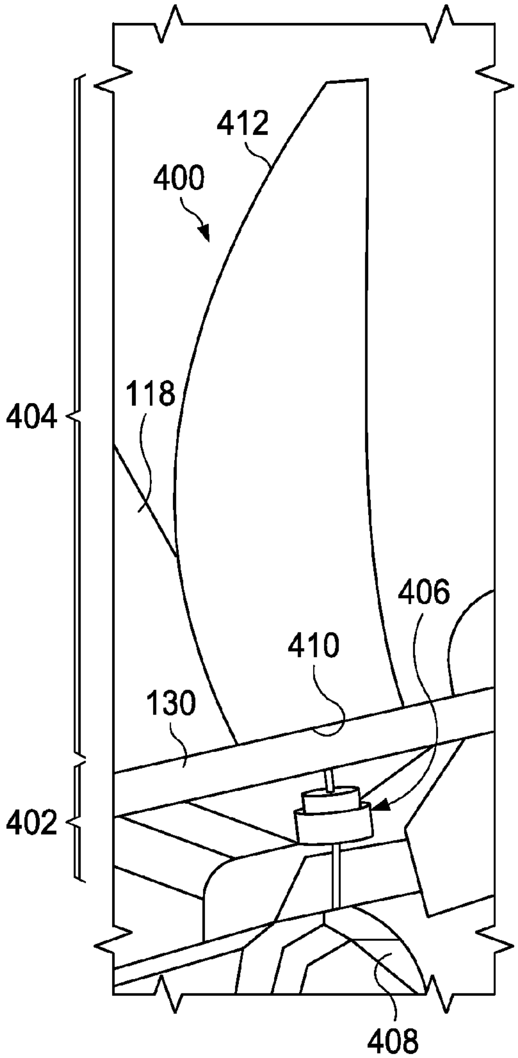
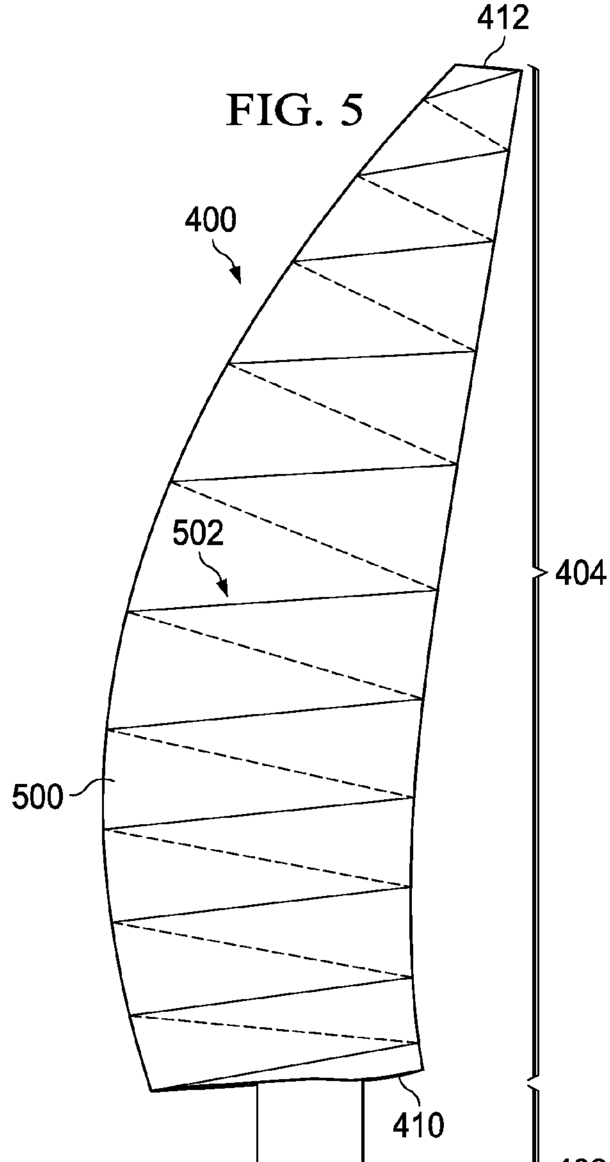


FIG. 5



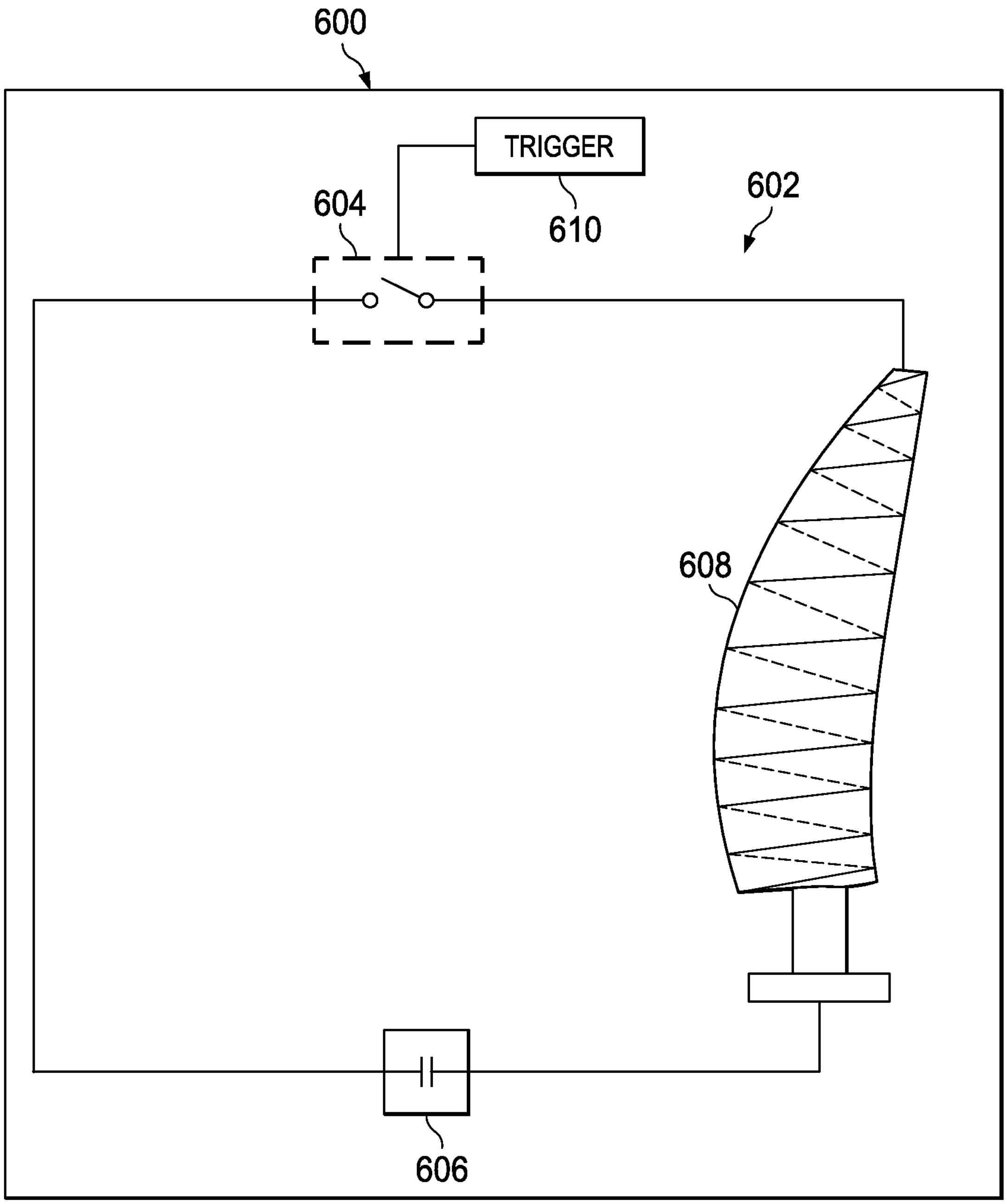


FIG. 6

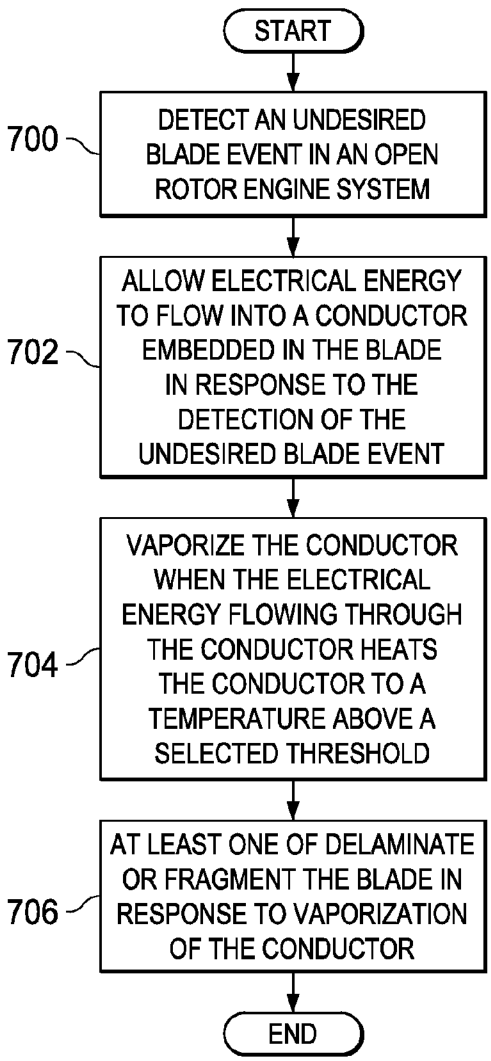

START
DETECT AN UNDESIRED BLADE EVENT IN AN OPEN ROTOR ENGINE SYSTEM
700
ALLOW ELECTRICAL ENERGY TO FLOW INTO A CONDUCTOR EMBEDDED IN THE BLADE IN RESPONSE TO THE DETECTION OF THE UNDESIRED BLADE EVENT
702
VAPORIZE THE CONDUCTOR WHEN THE ELECTRICAL ENERGY FLOWING THROUGH THE CONDUCTOR HEATS THE CONDUCTOR TO A TEMPERATURE ABOVE A SELECTED THRESHOLD
704
AT LEAST ONE OF DELAMINATE OR FRAGMENT THE BLADE IN RESPONSE TO VAPORIZATION OF THE CONDUCTOR
706
END

FIG. 7

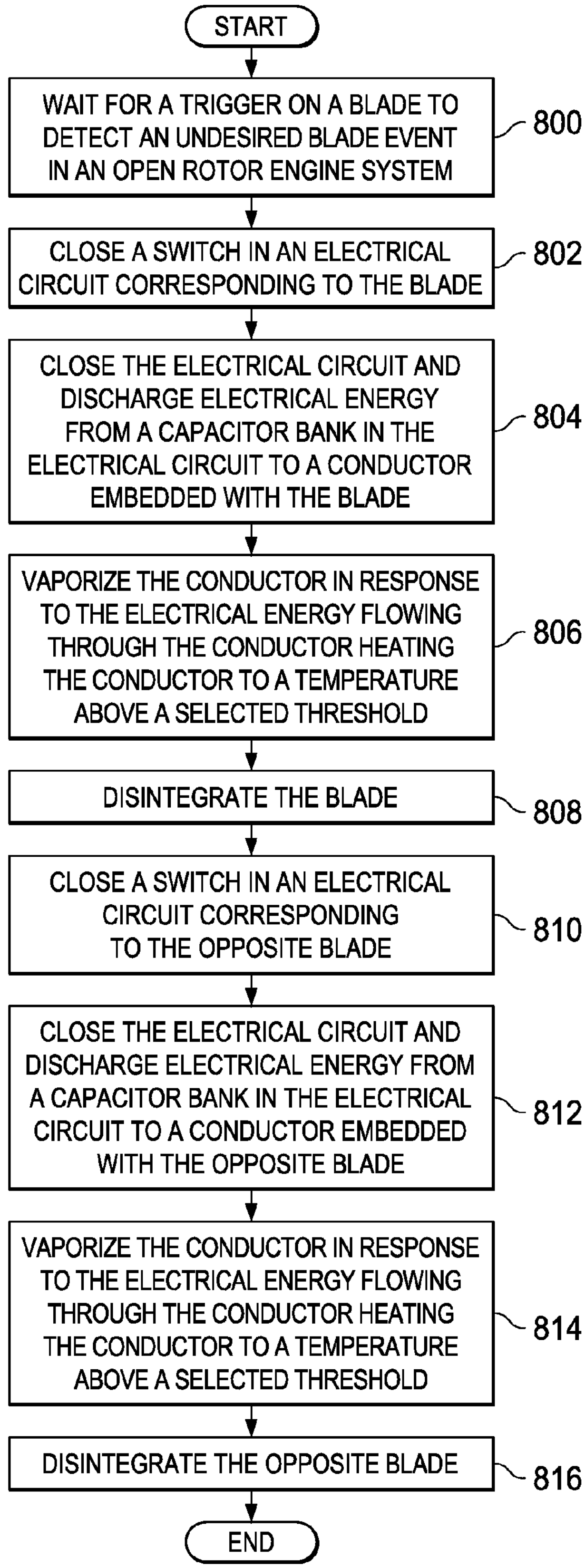

START
WAIT FOR A TRIGGER ON A BLADE TO DETECT AN UNDESIRED BLADE EVENT IN AN OPEN ROTOR ENGINE SYSTEM
800
CLOSE A SWITCH IN AN ELECTRICAL CIRCUIT CORRESPONDING TO THE BLADE
802
CLOSE THE ELECTRICAL CIRCUIT AND DISCHARGE ELECTRICAL ENERGY FROM A CAPACITOR BANK IN THE ELECTRICAL CIRCUIT TO A CONDUCTOR EMBEDDED WITH THE BLADE
804
VAPORIZE THE CONDUCTOR IN RESPONSE TO THE ELECTRICAL ENERGY FLOWING THROUGH THE CONDUCTOR HEATING THE CONDUCTOR TO A TEMPERATURE ABOVE A SELECTED THRESHOLD
806
DISINTEGRATE THE BLADE
808
CLOSE A SWITCH IN AN ELECTRICAL CIRCUIT CORRESPONDING TO THE OPPOSITE BLADE
810
CLOSE THE ELECTRICAL CIRCUIT AND DISCHARGE ELECTRICAL ENERGY FROM A CAPACITOR BANK IN THE ELECTRICAL CIRCUIT TO A CONDUCTOR EMBEDDED WITH THE OPPOSITE BLADE
812
VAPORIZE THE CONDUCTOR IN RESPONSE TO THE ELECTRICAL ENERGY FLOWING THROUGH THE CONDUCTOR HEATING THE CONDUCTOR TO A TEMPERATURE ABOVE A SELECTED THRESHOLD
814
DISINTEGRATE THE OPPOSITE BLADE
816
END

FIG. 8

FIG. 9

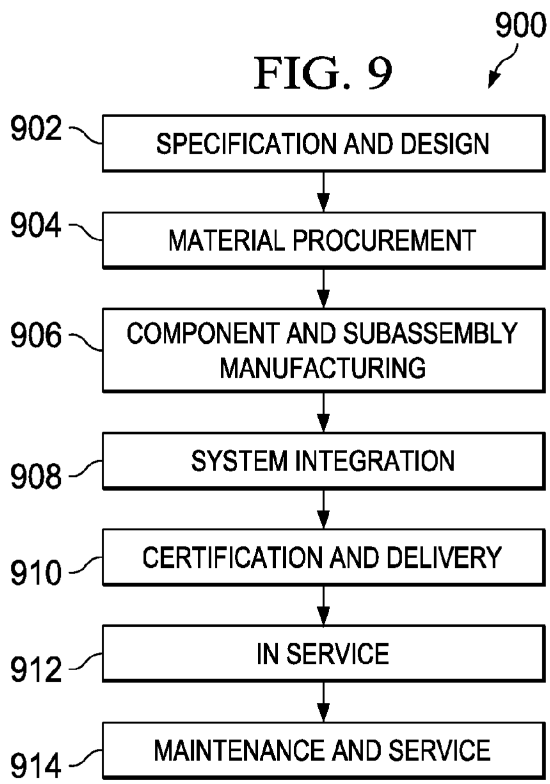
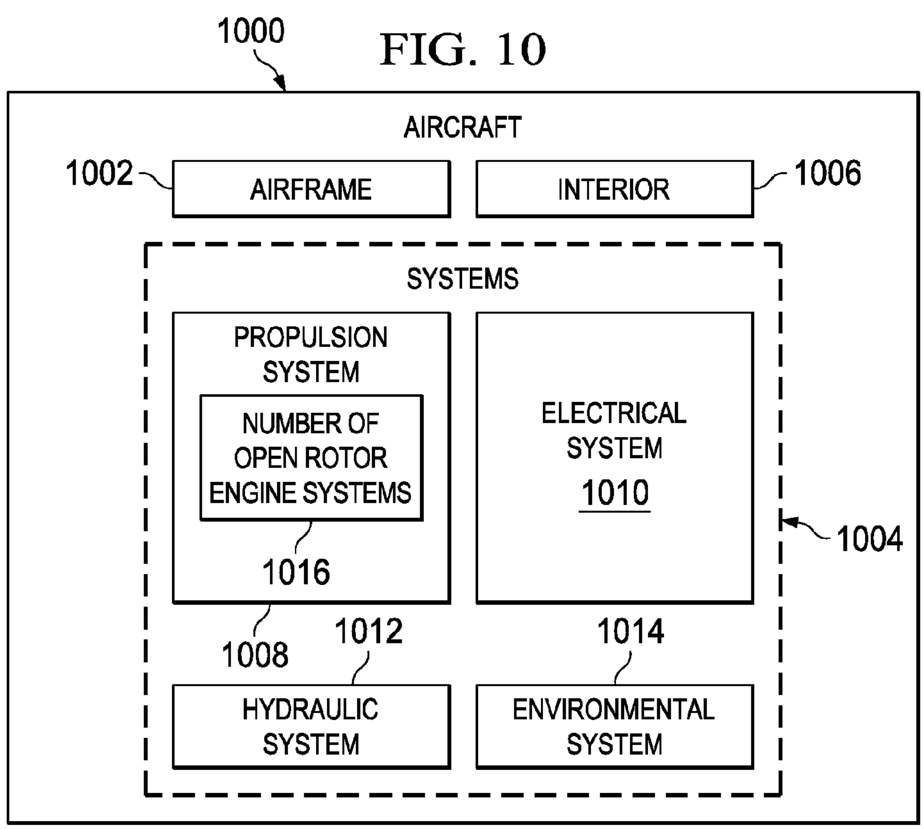

900
902
SPECIFICATION AND DESIGN
904
MATERIAL PROCUREMENT
906
COMPONENT AND SUBASSEMBLY MANUFACTURING
908
SYSTEM INTEGRATION
910
CERTIFICATION AND DELIVERY
912
IN SERVICE
914
MAINTENANCE AND SERVICE

FIG. 10


1000
AIRCRAFT
1002
AIRFRAME
INTERIOR
1006
SYSTEMS
PROPULSION SYSTEM
NUMBER OF OPEN ROTOR ENGINE SYSTEMS
1016
ELECTRICAL SYSTEM
1010
1004
1008
1012
1014
HYDRAULIC SYSTEM
ENVIRONMENTAL SYSTEM

BLADE SAFETY MECHANISM FOR OPEN ROTOR ENGINE SYSTEM

BACKGROUND INFORMATION

1. Field

The present disclosure relates generally to engine systems and, in particular, to open rotor engine systems. Still more particularly, the present disclosure relates to a safety mechanism for handling an undesired blade event in an open rotor engine system.

2. Background

An open rotor engine system is an engine system in which the propeller of the engine system is not contained within the nacelle, or housing, of the engine system. The propeller, which may be also referred to as a fan, is formed by blades connected to a hub. These blades may also be referred to as rotor blades, propeller blades, or fan blades. Rotation of a portion of the hub causes the blades to rotate about an axis through the hub.

With an open rotor engine system, the overall diameter of the propeller may be increased and the overall weight of the engine system reduced. In particular, with an open rotor engine system, the nacelle, seen typically with turbofan engines, may not be needed. Removal of the nacelle may reduce the weight of the engine system and reduce the overall drag induced by the engine system.

Depending on the configuration, an open rotor engine system may have a single propeller or a pair of propellers. The pair of propellers may include a first propeller formed by a first set of blades that rotate in one direction and a second propeller formed by a second set of blades that rotate in the opposite direction.

Prior to usage of an open rotor engine system in an aircraft, the open rotor engine system may need to be certified by one or more regulation agencies, such as, for example, the Federal Aviation Administration (FAA). Certification may require that a safety measure be in place to handle a blade release event. As used herein, a "blade release event" may be a separation of a blade from the hub of the open rotor engine system or a separation of some portion of the blade from the rest of the blade. In particular, certification of the open rotor engine system may require that a safety measure be present to prevent or reduce the possibility of a blade release event having one or more undesired effects on the aircraft and/or on another open rotor engine system of the aircraft.

Additionally, in some cases, certification may require that the aerodynamic influences and/or out-of-balance vibrations caused by a blade release event should have a limited effect on the controllability of the aircraft. Therefore, it would be desirable to have a method and apparatus that take into account at least some of the issues discussed above, as well as other possible issues.

SUMMARY

In one illustrative embodiment, an apparatus comprises a blade, a conductor embedded within the blade, and an activation system. The blade is connected to a hub in an open rotor engine system. The activation system is configured to allow electrical energy to flow into the conductor in response to an undesired blade event such that the conductor vaporizes.

In another illustrative embodiment, an open rotor engine system comprises a hub, a plurality of blades, and an activation system. A blade in the plurality of blades comprises a conductor embedded within the blade. The activation system is configured to allow electrical energy to flow into the conductor in response to an undesired blade event such that the conductor vaporizes and the blade at least one of delaminates or fragments.

In yet another illustrative embodiment, a method is provided for handling an undesired blade event. An occurrence of an undesired blade event in an open rotor engine system is detected. Electrical energy is allowed to flow into a conductor embedded in the blade in response to detection of the undesired blade event. The conductor is vaporized when the electrical energy flowing through the conductor heats the conductor to a temperature above a selected threshold.

The features and functions can be achieved independently in various embodiments of the present disclosure or may be combined in yet other embodiments in which further details can be seen with reference to the following description and drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

The novel features believed characteristic of the illustrative embodiments are set forth in the appended claims. The illustrative embodiments, however, as well as a preferred mode of use, further objectives and features thereof, will best be understood by reference to the following detailed description of an illustrative embodiment of the present disclosure when read in conjunction with the accompanying drawings, wherein:

FIG. **1** is an illustration of an aircraft in accordance with an illustrative embodiment;

FIG. **2** is an illustration of an engine system in the form of a block diagram in accordance with an illustrative embodiment;

FIG. **3** is an illustration of an activation device in the form of a block diagram in accordance with an illustrative embodiment;

FIG. **4** is an illustration of an enlarged view of a blade in accordance with an illustrative embodiment;

FIG. **5** is an illustration of a blade in accordance with an illustrative embodiment;

FIG. **6** is an illustration of a schematic representation of an activation device in accordance with an illustrative embodiment;

FIG. **7** is an illustration of a process for handling an undesired blade event in the form of a flowchart in accordance with an illustrative embodiment;

FIG. **8** is an illustration of a process for handling an undesired blade event in the form of a flowchart in accordance with an illustrative embodiment;

FIG. **9** is an illustration of an aircraft manufacturing and service method in the form of a flowchart in accordance with an illustrative embodiment; and

FIG. **10** is an illustration of an aircraft in the form of a block diagram in accordance with an illustrative embodiment.

DETAILED DESCRIPTION

The illustrative embodiments recognize and take into account different considerations. For example, the illustrative embodiments recognize and take into account that one method for handling a blade release event may involve positioning an open rotor engine system at a location along an aircraft in which any undesired effects of the blade release may be minimized. However, the illustrative embodiments recognize and take into account that the locations along the aircraft at which the open rotor engine system may be positioned may be limited by the size of the aircraft, a desired center of mass location for the aircraft, a desired level of aerodynamic performance for the aircraft, and/or other types of factors.

Another method for handling a blade release event may include adding shielding to portions of the aircraft that may be affected by the blade release. For example, shielding may be added to the portion of a fuselage that may be impacted by a blade that has separated from the hub of the open rotor engine system. However, the illustrative embodiments also recognize and take into account this type of shielding may increase the weight of the aircraft more than desired. Additionally, in some cases, the shielding may affect the aerodynamic performance of the aircraft.

Thus, the illustrative embodiments described below provide a blade safety mechanism that may be used to safely handle blade release events and/or other types of undesired blade events. The blade safety mechanism described in the figures below may not increase the weight of the aircraft beyond selected tolerances. Further, this blade safety mechanism may not affect the aerodynamic performance of the aircraft outside of selected tolerances.

Referring now to the figures and, in particular, with reference to FIG. **1**, an illustration of an aircraft is depicted in accordance with an illustrative embodiment. In this illustrative example, aircraft **100** has wing **102** and wing **104** attached to body **106**. Body **106** of aircraft **100** has tail section **108**. Horizontal stabilizer **110**, horizontal stabilizer **112**, and vertical stabilizer **114** are attached to tail section **108** of body **106**.

As depicted, aircraft **100** includes open rotor engine system **116** attached to wing **102** and open rotor engine system **118** attached to wing **104**. Open rotor engine system **116** includes propeller **120** and propeller **122**, which are both associated with nacelle **124**. Open rotor engine system **118** includes propeller **126** and propeller **128**, which are both associated with nacelle **130**.

As used herein, when one component is "associated" with another component, the association is a physical association in the depicted examples. For example, a first component, such as propeller **120**, may be considered to be associated with a second component, such as nacelle **124**, by being secured to the second component, bonded to the second component, mounted to the second component, welded to the second component, fastened to the second component, and/or connected to the second component in some other suitable manner. The first component also may be connected to the second component using a third component. Further, the first component may be considered to be associated with the second component by being formed as part of and/or as an extension of the second component.

Open rotor engine system **116** and open rotor engine system **118** both have blade safety mechanisms configured to handle blade release events. Area **132** indicates the area around body **106** of aircraft **100** into which a blade may enter once the blade has separated from a hub inside the nacelle of the corresponding open rotor engine system. The blade safety mechanisms cause disintegration of at least one blade in response to any undesired blade event that occurs with a particular blade such that the particular blade is prevented from impacting body **106** of aircraft **100** within area **132** or, in some cases, outside area **132**.

With reference now to FIG. **2**, an illustration of an engine system is depicted in the form of a block diagram in accordance with an illustrative embodiment. Engine system **200** may be used to move vehicle **202**. Vehicle **202** may be any platform configured to move. In one illustrative example, vehicle **202** takes the form of aerial vehicle **204**. Aerial vehicle **204** may take the form of, for example, without limitation, aircraft **205**, unmanned aerial vehicle **206**, or some other type of air-based vehicle. Aircraft **100** in FIG. **1** may be an example of one implementation for aircraft **205** in FIG. **2**.

In this illustrative example, engine system **200** takes the form of open rotor engine system **208**. Open rotor engine system **116** and open rotor engine system **118** in FIG. **1** are examples of implementations for open rotor engine system **208** in FIG. **2**.

As depicted, open rotor engine system **208** may include nacelle **210**, propeller **212**, hub **214**, and engine core **215**. Propeller **212** is located outside of nacelle **210**. Hub **214** and engine core **215** are located within nacelle **210**. Propeller **212** may be associated with nacelle **210** by being connected to hub **214**. In this illustrative example, open rotor engine system **208** includes only one propeller. However, in other illustrative examples, open rotor engine system **208** may include more than one propeller. Propellers **120**, **122**, **126**, and **128** in FIG. **1** are examples of implementations for propeller **212** in FIG. **2**.

Propeller **212** is formed by plurality of blades **216**. Blade **218** is an example of one of plurality of blades **216**. As depicted, blade **218** is comprised of layers **220**. In one illustrative example, layers **220** may take the form of composite layers **222**. Each of composite layers **222** may be comprised of one or more composite materials. As one illustrative example, each of composite layers **222** may be a layer of a carbon fiber. These layers of carbon fiber may have been cured to form a solid carbon fiber blade. Composite layers **222** may also be referred to as composite plies.

Open rotor engine system **208** also includes blade safety mechanism **224**. Blade safety mechanism **224** is configured to handle undesired blade event **225**. Undesired blade event **225** may comprise at least one of a separation of one of plurality of blades **216** from hub **214**, a bifurcation of one of plurality of blades **216** along a length of the blade, a separation of some portion of a segment of a blade from the rest of the blade, or some other type of undesired blade event. In this manner, blade safety mechanism **224** is configured to safely handle blade release events and other types of undesired blade events.

As depicted, blade safety mechanism **224** includes plurality of conductors **226** and activation system **228**. Conductor **230** is an example of one of plurality of conductors **226**. Conductor **230** may be comprised of number of conductive elements **232**. As used herein, a "number of" items may include one or more items. In this manner, number of conductive elements **232** may include one or more conductive elements.

A "conductive element," as used herein, such as one of number of conductive elements **232**, may be an object or piece of material that allows the flow of electric charges in one or more directions. In other words, a conductive element may be an element that allows electricity to pass through the element. In this illustrative example, number of conductive elements **232** may include at least one of a conductive wire, a conductive thread, a conductive filament, a conductive fiber, a conductive patch of material, a conductive mesh, or some other type of conductive object or piece of material.

As used herein, the phrase "at least one of," when used with a list of items, means different combinations of one or more of the listed items may be used but only one item in the list of items may be needed. The item may be a particular object, thing, or category. In other words, "at least one of" means that any combination of items and any number of items may be used from the list but not all of the items in the list are required.

For example, "at least one of item A, item B, or item C" may include, without limitation, item A, item A and item B, or only item B. For example, "at least one of item A, item B, or item C" may include, without limitation, item A; both item A and item B; item A, item B, and item C; or item B and item C. In other examples, "at least one of" may be, for example, without limitation, two of item A, one of item B, and ten of item C; four of item B and seven of item C; or some other type of combination.

In one illustrative example, number of conductive elements **232** may be implemented using number of wire elements **233**. Number of wire elements **233** may be one or more metallic wires such as, for example, without limitation, one or more copper wires.

Conductor **230** may be embedded within blade **218** in this illustrative example. In one illustrative example, conductor **230** may be embedded between layers **220** of blade **218**. In this example, conductor **230** may not be exposed on the outer surface of blade **218**. However, in other illustrative examples, some portion of conductor **230** may be exposed on the outer surface of blade **218**.

When layers **220** takes the form of composite layers **222**, number of conductive elements **232** may be arranged at least one of substantially parallel to the fibers running through composite layers **222** or substantially orthogonal to the fibers running through composite layers **222**. In one illustrative example, number of conductive elements **232** may traverse blade **218** in a chord-wise direction so that number of conductive elements **232** may be unaffected by span-wise strain within blade **218**.

In some cases, number of conductive elements **232** may be implemented using a single wire that is wound around a portion of layers **220** of blade **218**. This wire may be wound around blade **218** in a spiral of, for example, about 5 degrees to about 20 degrees.

Conductor **230** is electrically connected to activation system **228**. As used herein, when a first component, such as conductor **230**, is "electrically connected" to a second component, such as activation system **228**, the first component is connected to the second component such that an electrical current, or electrical energy, may flow from the first component to the second component, from the second component to the first component, or a combination of the two. In some cases, the first component may be electrically connected to the second component without any additional components between the two components. In other cases, the first component may be electrically connected to the second component by one or more other components.

When more than one conductive element is used to form conductor **230**, these conductive elements may be electrically connected to each other with at least one of the conductive elements being electrically connected to activation system **228**. However, in some cases, at least a portion of these conductive elements may not be electrically connected to each other and may be independently electrically connected to activation system **228**.

As depicted, activation system **228** may include plurality of activation devices **234**. In one illustrative example, each of plurality of activation devices **234** may be electrically connected to a corresponding one of plurality of conductors **226**. For example, activation device **236** in plurality of activation devices **234** may be electrically connected to conductor **230**.

Activation device **236** activates a safety measure in response to the occurrence of undesired blade event **225**. As one illustrative example, this safety measure may be activated in response to a partial separation or complete separation of blade **218**, in whole or in part, from hub **214**. Activation device **236** may detect undesired blade event **225** and allow electrical energy **238** to flow into conductor **230** in response to undesired blade event **225**. The flow of electrical energy **238** into and through conductor **230** heats conductor **230** to a temperature above a selected threshold such that conductor **230** vaporizes.

As used herein, when an object "vaporizes," the object is converted into one or more gases, with both thermal energy and a shock wave being released. These molecules of the one or more gases may be ionized such that hot plasma is formed. In this illustrative example, when conductor **230** "vaporizes," conductor **230** is converted into plasma, thereby releasing thermal energy and a shock wave that is experienced within blade **218**.

The release of thermal energy and the shock wave within blade **218** causes blade **218** to at least one or portion of one delaminate or fragment. When blade **218** "delaminates," layers **220** in blade **218** may divide or separate from each other. When blade **218** "fragments," blade **218** is broken up into smaller portions. In some cases, the delamination and/or fragmentation of blade **218** may be referred to as the disintegration of blade **218**.

In one illustrative example, plurality of activation devices **234** may be located on the rotating portion of hub **214**. In this example, number of slip rings **240** may be used to transfer electrical energy generated by power source **242** within nacelle **210** to plurality of activation devices **234**.

In some cases, the activation of the safety measure for blade **218** by activation device **236** may cause the activation of a similar safety measure for opposite blade **244**. Opposite blade **244** may be the blade located directly opposite of blade **218** with respect to a center axis through hub **214**.

For example, the release of electrical energy **238** into conductor **230** by activation device **236** may trigger a blade event for opposite blade **244**. This blade event may be, for example, the separation of opposite blade **244** from hub **214**. Separation of opposite blade **244** from hub **214** may result in the activation device in plurality of activation devices **234** corresponding to opposite blade **244** releasing electrical energy into the conductor in plurality of conductors **226** embedded within opposite blade **244**. In this manner, opposite blade **244** may be at least one of delaminated or fragmented. This process may reduce the out-of-balance vibration caused by blade **218** separating from hub **214**. Reducing this out-of-balance vibration may reduce and/or prevent the possibility of undesired structural effects on aircraft **205** and/or the loss of control of aircraft **205**.

With reference now to FIG. **3**, an illustration of activation device **236** from FIG. **2** is depicted in the form of a block diagram in accordance with an illustrative embodiment. In one illustrative example, activation device **236** is implemented using electrical circuit **300**. Electrical circuit **300** may include capacitor bank **302**, switch **304**, and trigger **306**. In some cases, conductor **230** may be considered part of electrical circuit **300**.

As depicted, capacitor bank **302** may be formed using number of capacitors **308**. Number of capacitors **308** may be electrically connected to conductor **230** such that electrical energy **238** stored within number of capacitors **308** may be sent into conductor **230**.

Capacitor bank **302** may be charged using, for example, without limitation, number of slip rings **240**, to increase electrical energy **238** stored within capacitor bank **302**. For example, number of slip rings **240** may send a current into capacitor bank **302** to charge capacitor bank **302**. Capacitor bank **302** may be charged until at least selected level **309** of electrical energy **238** has been reached. Selected level **309** may be the level of electrical energy **238** needed to be sent into conductor **230** in FIG. **2** in order to cause vaporization of conductor **230**.

When blade **218** is connected to hub **214** in FIG. **2**, switch **304** is open. When switch **304** is open, electrical circuit **300** is open and electrical energy **238** is prevented from being sent into conductor **230**. However, when switch **304** is closed, electrical circuit **300** is closed and capacitor bank **302** may discharge electrical energy **238** into conductor **230**. Switch **304** is controlled using trigger **306**. In this manner, trigger **306** is used to initiate the release of electrical energy **238** into conductor **230**. In particular, trigger **306** is used to detect undesired blade event **225** in FIG. **2** and close switch **304** in response to a detection of undesired blade event **225** occurring.

Trigger **306** and switch **304** are configured such that electrical circuit **300** is closed quickly enough to allow selected level **309** of electrical energy **238** to be discharged from capacitor bank **302** into conductor **230** before the electrical connection between capacitor bank **302** and conductor **230** is severed.

In one illustrative example, trigger **306** is implemented using number of trigger elements **310**. Number of trigger elements **310** may be connected to at least one of blade **218** and hub **214**. Number of trigger elements **310** may be, for example, a number of trigger wires. When blade **218** is connected to hub **214**, number of trigger elements **310** remains intact. When blade **218** separates from hub **214**, number of trigger elements **310** breaks. The breaking of number of trigger elements **310** causes switch **304** to close.

For example, number of trigger elements **310** may be implemented as a single, brittle wire located on the outer surface of blade **218** and connected to switch **304**. This wire may be placed along the length of the blade **218** such that the wire traverses from the base of blade **218** to the tip of blade **218**, returning several times such that the wire covers the entire perimeter of blade **218**. Of course, depending on the implementation, the wire may be arranged along blade **218** in some other manner. The wire may be selected such that the brittleness of the wire causes the wire to break just above the threshold for the occurrence of undesired blade event **225**.

As one illustrative example, the separation of blade **218** from hub **214** or the separation of a portion of blade **218** from the rest of blade **218** may cause undesired effects within blade **218**. The brittle wire may be configured to respond to these undesired effects and break when the threshold for these undesired effects has been reached.

Switch **304** may be implemented in a number of different ways. In one illustrative example, switch **304** takes the form of solenoid switch **312**. The breaking of number of trigger elements **310** may remove the electrical current being supplied to solenoid switch **312**, thereby causing solenoid switch **312** to close. The closing of solenoid switch **312** may then, in turn, cause electrical current to flow into conductor **230** embedded within blade **218**.

In another illustrative example, switch **304** takes the form of spring-loaded switch **314**. Spring-loaded switch **314** includes first spring-loaded contact **316**, second spring-loaded contact **318**, and insulator **320**. First spring-loaded contact **316** and second spring-loaded contact **318** are biased towards each other. However, insulator **320** is located between first spring-loaded contact **316** and second spring-loaded contact **318**. In particular, insulator **320** is used to separate first spring-loaded contact **316** and second spring-loaded contact **318**.

Insulator **320** may be implemented using any object or piece of material configured to block the flow of electrical current between first spring-loaded contact **316** and second spring-loaded contact **318**. In one illustrative example, insulator **320** takes the form of a ceramic block.

When switch **304** takes the form of spring-loaded switch **314**, trigger **306** may be implemented using tether **322**. Tether **322** may be connected to insulator **320**. Tether **322** is configured to move insulator **320** such that insulator **320** no longer separates first spring-loaded contact **316** and second spring-loaded contact **318**. In this manner, first spring-loaded contact **316** may be allowed to contact second spring-loaded contact **318**, thereby closing electrical circuit **300** and causing electrical current to flow into conductor **230** embedded within blade **218**.

The illustrations of vehicle **202** and open rotor engine system **208** in FIG. **2** and activation device **236** are not meant to imply physical or architectural limitations to the manner in which an illustrative embodiment may be implemented. Other components in addition to or in place of the ones illustrated may be used. Some components may be optional. Also, the blocks are presented to illustrate some functional components. One or more of these blocks may be combined, divided, or combined and divided into different blocks when implemented in an illustrative embodiment.

For example, in some cases, blade safety mechanism **224** in FIG. **2** may be used to safely handle undesired blade events occurring with one or more other propellers of open rotor engine system **208** in addition to propeller **212** in FIG. **2**. In other illustrative examples, number of slip rings **240** may not be needed to supply electrical energy to activation system **228** in FIG. **2**.

In some illustrative examples, some other type of switch **304** may be used. For example, switch **304** may be implemented using a plasma switch in some cases. In still other illustrative examples, a stationary contact may be used in the place of second spring-loaded contact **318** or first spring-loaded contact **316**.

With reference now to FIG. **4**, an illustration of an enlarged view of a blade is depicted in accordance with an illustrative embodiment. Blade **400** in FIG. **4** may be one of the blades that forms propeller **128** in FIG. **1**. In this illustrative example, blade **400** has root section **402** and airfoil section **404**.

As depicted, root section **402** of blade **400** is located within nacelle **130** of open rotor engine system **118** but airfoil section **404** of blade **400** extends outside of nacelle **130**. Root section **402** includes attachment unit **406** that is used to attach root section **402** of blade **400** to hub **408**. Airfoil section **404** has base **410** and tip **412**.

With reference now to FIG. **5**, an illustration of blade **400** from FIG. **4** is depicted in accordance with an illustrative embodiment. In FIG. **5**, one or more of the outermost layers used to form blade **400** have been removed such that conductor **500** around inner layers **502** of blade **400** may be more clearly seen. In this illustrative example, conductor **500** is a wire that has been wound around inner layers **502** of blade **400**.

Turning now to FIG. **6**, an illustration of a schematic representation of an activation device is depicted in accordance with an illustrative embodiment. In FIG. **6**, activation device **600** is an example of one implementation for activation device **236** in FIGS. **2-3**. In this illustrative example, activation device **236** is implemented using electrical circuit **602**. Electrical circuit **602** is an example of one implementation for electrical circuit **300** in FIG. **3**.

As depicted, electrical circuit **602** includes switch **604**, capacitor bank **606**, conductor **608**, and trigger **610**. Trigger **610** is configured to control switch **604**. Trigger **610** closes switch **604** in response to an undesired blade event. When switch **604** closes, electrical circuit **602** is then closed and at least a portion of the electrical energy stored in capacitor bank **606** is allowed to flow into conductor **608**. When switch **604** is open, electrical energy is not allowed to flow into conductor **608**.

The illustrations of blade **400** in FIGS. **4-5** and activation device **600** in FIG. **6** are not meant to imply physical or architectural limitations to the manner in which an illustrative embodiment may be implemented. Other components in addition to or in place of the ones illustrated may be used. Some components may be optional.

The different components shown in FIGS. **4-6** may be illustrative examples of how components shown in block form in FIGS. **2-3** can be implemented as physical structures. Additionally, some of the components in FIGS. **4-6** may be combined with components in FIGS. **2-3**, used with components in FIGS. **2-3**, or a combination of the two.

With reference now to FIG. **7**, an illustration of a process for handling an undesired blade event is depicted in the form of a flowchart in accordance with an illustrative embodiment. The process illustrated in FIG. **7** may be performed using a blade safety mechanism such as, for example, without limitation, blade safety mechanism **224** in FIG. **2**.

The process begins by detecting an undesired blade event in an open rotor engine system (operation **700**). Next, electrical energy is allowed to flow into a conductor embedded in the blade in response to detection of the undesired blade event (operation **702**). The conductor may be comprised of, for example, one or more metallic wires.

The conductor is vaporized when the electrical energy flowing through the conductor heats the conductor to a temperature above a selected threshold (operation **704**). When operation **704** is performed, the vaporization of the conductor results in a release of thermal energy and a shock wave within the blade. The blade at least one of delaminates or fragments in response to vaporization of the conductor (operation **706**), with the process terminating thereafter.

With reference now to FIG. **8**, an illustration of a process for handling an undesired blade event is depicted in the form of a flowchart in accordance with an illustrative embodiment. The process described in FIG. **8** may be a more detailed version of the process described in FIG. **7**.

The process begins by waiting for a trigger on a blade to detect an undesired blade event in an open rotor engine system (operation **800**). In response to the trigger detecting the undesired blade event, the trigger closes a switch in an electrical circuit corresponding to the blade (operation **802**). In response to the switch closing, the electrical circuit is closed and electrical energy is discharged from a capacitor bank in the electrical circuit to a conductor embedded with the blade (operation **804**).

The conductor is vaporized in response to the electrical energy flowing through the conductor heating the conductor to a temperature above a selected threshold (operation **806**). In response to the conductor vaporizing, the blade disintegrates (operation **808**). In operation **808**, the blade may disintegrate by delaminating and/or fragmenting.

Additionally, in response to the trigger detecting the undesired blade event, another trigger for the opposite blade located directly opposite of the blade may close a switch in an electrical circuit corresponding to the opposite blade (operation **810**). In response to this switch closing, the electrical circuit is closed and electrical energy is discharged from a capacitor bank in the electrical circuit to a conductor embedded with the opposite blade (operation **812**).

The conductor is vaporized in response to the electrical energy flowing through the conductor heating the conductor to a temperature above a selected threshold (operation **814**). In response to the conductor vaporizing, the opposite blade disintegrates (operation **816**). In operation **816**, the blade may disintegrate by delaminating and/or fragmenting. Once operation **808** and operation **816** have been performed, the process terminates.

Of course, in other illustrative examples, the disintegration of the opposite blade in response to the triggering of the disintegration of the blade may be performed in some other manner. For example, pairs of opposing blades in the open rotor engine system may be wired in parallel to the trigger of each blade. In this manner, when the trigger of one blade detects an undesired blade event, the electrical circuits for both blades are closed simultaneously and in parallel.

Illustrative embodiments of the disclosure may be described in the context of aircraft manufacturing and service method **900** as shown in FIG. **9** and aircraft **1000** as shown in FIG. **10**. Turning first to FIG. **9**, an illustration of an aircraft manufacturing and service method is depicted in the form of a flowchart in accordance with an illustrative embodiment. During pre-production, aircraft manufacturing and service method **900** may include specification and design **902** of aircraft **1000** in FIG. **10** and material procurement **904**.

During production, component and subassembly manufacturing **906** and system integration **908** of aircraft **1000** in FIG. **10** takes place. Thereafter, aircraft **1000** in FIG. **10** may go through certification and delivery **910** in order to be placed in service **912**. While in service **912** by a customer, aircraft **1000** in FIG. **10** is scheduled for routine maintenance and service **914**, which may include modification, reconfiguration, refurbishment, and other maintenance or service.

Each of the processes of aircraft manufacturing and service method **900** may be performed or carried out by a system integrator, a third party, and/or an operator. In these examples, the operator may be a customer. For the purposes of this description, a system integrator may include, without limitation, any number of aircraft manufacturers and major-system subcontractors; a third party may include, without limitation, any number of vendors, subcontractors, and suppliers; and an operator may be an airline, a leasing company, a military entity, a service organization, and so on.

With reference now to FIG. **10**, an illustration of an aircraft is depicted in the form of a block diagram in which an illustrative embodiment may be implemented. In this example, aircraft **1000** is produced by aircraft manufacturing and service method **900** in FIG. **9** and may include airframe **1002** with plurality of systems **1004** and interior **1006**. Examples of systems **1004** include one or more of propulsion system **1008**, electrical system **1010**, hydraulic system **1012**, and environmental system **1014**. Any number of other systems may be included. Although an aerospace example is shown, different illustrative embodiments may be applied to other industries, such as the automotive industry.

Apparatuses and methods embodied herein may be employed during at least one of the stages of aircraft manufacturing and service method **900** in FIG. **9**. For example, propulsion system **1008** may include number of open rotor engine systems **1016**. Each of these open rotor engine systems **1016** may be implemented in manner similar to, for example, open rotor engine system **208** described in FIG. **2**. A blade safety mechanism, such as blade safety mechanism **224** in FIG. **2**, may be installed during component and subassembly manufacturing **906**, system integration **908**, routine maintenance and service **914**, or some other stage in aircraft manufacturing and service method **900**.

In one illustrative example, components or subassemblies produced in component and subassembly manufacturing **906** in FIG. **9** may be fabricated or manufactured in a manner similar to components or subassemblies produced while aircraft **1000** is in service **912** in FIG. **9**. As yet another example, one or more apparatus embodiments, method embodiments, or a combination thereof may be utilized during production stages, such as component and subassembly manufacturing **906** and system integration **908** in FIG. **9**. One or more apparatus embodiments, method embodiments, or a combination thereof may be utilized while aircraft **1000** is in service **912** and/or during maintenance and service **914** in FIG. **9**. The use of a number of the different illustrative embodiments may substantially expedite the assembly of and/or reduce the cost of aircraft **1000**.

The flowcharts and block diagrams in the different depicted embodiments illustrate the architecture, functionality, and operation of some possible implementations of apparatuses and methods in an illustrative embodiment. In this regard, each block in the flowcharts or block diagrams may represent a module, a segment, a function, and/or a portion of an operation or step.

In some alternative implementations of an illustrative embodiment, the function or functions noted in the blocks may occur out of the order noted in the figures. For example, in some cases, two blocks shown in succession may be executed substantially concurrently, or the blocks may sometimes be performed in the reverse order, depending upon the functionality involved. Also, other blocks may be added in addition to the illustrated blocks in a flowchart or block diagram.

The description of the different illustrative embodiments has been presented for purposes of illustration and description, and is not intended to be exhaustive or limited to the embodiments in the form disclosed. Many modifications and variations will be apparent to those of ordinary skill in the art. Further, different illustrative embodiments may provide different features as compared to other desirable embodiments. The embodiment or embodiments selected are chosen and described in order to best explain the principles of the embodiments, the practical application, and to enable others of ordinary skill in the art to understand the disclosure for various embodiments with various modifications as are suited to the particular use contemplated.

What is claimed is:

1. An apparatus comprising:

a blade connected to a hub in an open rotor engine system;

a conductor embedded within the blade and extending a length of an airfoil section of the blade; and

an activation system configured to allow electrical energy to flow into the conductor in response to an undesired blade event such that the conductor vaporizes.

2. The apparatus of claim **1**, wherein the undesired blade event comprises at least one of a separation of the blade from the hub, a bifurcation of the blade along a length of the blade, and a separation of a portion of the blade from a rest of the blade.

3. The apparatus of claim **1**, wherein the blade is comprised of a plurality of composite layers and wherein the conductor is embedded between layers of the plurality of composite layers.

4. The apparatus of claim **1**, wherein the conductor vaporizing causes the blade to at least one of delaminate or fragment.

5. The apparatus of claim **1**, wherein the activation system comprises:

an electrical circuit, wherein the electrical energy is allowed to flow into the conductor when the electrical circuit is closed.

6. The apparatus of claim **5**, wherein the electrical circuit comprises:

a capacitor bank configured to store the electrical energy that is released into the conductor; and

a switch configured to close the electrical circuit in response to the undesired blade event such that the electrical energy stored in the capacitor bank is discharged into the conductor.

7. The apparatus of claim **6**, wherein the capacitor bank is attached to a rotating portion of the hub.

8. The apparatus of claim **7**, wherein the capacitor bank is charged using a number of slip rings connected to a power source located within the open rotor engine system.

9. The apparatus of claim **6**, wherein the activation system further comprises:

a trigger configured to close the switch in response to the undesired blade event.

10. The apparatus of claim **9**, wherein the trigger comprises a number of trigger elements.

11. The apparatus of claim **6**, wherein the switch is a solenoid switch.

12. The apparatus of claim **6**, wherein the switch is a spring-loaded switch comprising:

a first spring-loaded contact;

a second spring-loaded contact; and

an insulator located between the first spring-loaded contact and the second spring-loaded contact, wherein the insulator separates the first spring-loaded contact from the second spring-loaded contact and wherein moving the insulator allows the first spring-loaded contact to contact the second spring-loaded contact and close the electrical circuit.

13. The apparatus of claim **1**, wherein the blade is comprised of layers and wherein the conductor is a wire wound around a portion of interior composite layers that form the blade.

14. The apparatus of claim **1**, wherein the conductor is comprised of a number of conductive elements connected to each other.

15. An open rotor engine system comprising:

a hub;

a plurality of blades in which a blade in the plurality of blades comprises a conductor embedded within the blade and extending a length of an airfoil section of the blade; and

an activation system configured to allow electrical energy to flow into the conductor in response to an undesired blade event such that the conductor vaporizes and the blade at least one of delaminates or fragments.

16. The open rotor engine system of claim **15**, wherein the activation system is further configured to allow the electrical energy to flow into another conductor embedded in an opposite blade located opposite to the blade with respect to a center axis through the hub such that the another conductor vaporizes and the opposite blade at least one of delaminates or fragments.

17. A method comprising:

detecting an occurrence of an undesired blade event in an open rotor engine system;

allowing electrical energy to flow into a conductor embedded in a blade and extending a length of an airfoil section of the blade in response to detection of the undesired blade event; and

vaporizing the conductor when the electrical energy flowing through the conductor heats the conductor to a temperature above a selected threshold.

18. The method of claim **17** further comprising:

disintegrating the blade by at least one of delaminating the blade and fragmenting the blade in response to the conductor vaporizing.

19. The method of claim **17**, wherein allowing the electrical energy to flow into the conductor embedded in the blade comprises:

closing an electrical circuit such that the electrical energy stored in a capacitor bank in the electrical circuit is discharged into the conductor.

20. The method of claim **19**, wherein closing the electrical circuit such that the electrical energy stored in the capacitor bank in the electrical circuit is discharged into the conductor comprises:

closing a switch in the electrical circuit in response to the undesired blade event, wherein closing the switch closes the electrical circuit.

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